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Design of Back Pressure Control Valve for Automotive Scroll Compressor

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ABSTRACT

The optimum design of back pressure chamber is one of the most important factors in designing scroll compressors because it has a great influence on the efficiency and other design parameters. The design process can be divided into 2 parts. One is obtaining the optimum pressure of the chamber and keeping it in constant value. The other is finding out the minimum inflow rate of medium with which back pressure chamber is filled. In this study we are focused on the first step.

At first we added a simple structure that can change back pressure without reassembling compressor. It makes possible to obtaining optimum back pressure. Then we devised an equipment that the back pressure control valve assembly could be independently tested with. Spring was redesigned to decrease stiffness variation. Also sealing mechanism of back pressure control valve was improved to more effective way.

As a result, it was verified that in a real mode test back pressure variation could be retained in 2.3% with discharge pressure and operating frequency varied. In addition the integrated structure of back pressure control valve is expected to contribute to effective manufacturing process.

1. INTRODUCTION

Recently as environmental problems becomes main issue, many car air-conditioner makers are interested in developing systems with alternative refrigerant in order to replace R134a which effects on global warming. Also as an effort to reduce CO₂ emission, biomass fuel is gradually replaced by fuel cell and hybrid cars. Fuel cell is eco-friendly because of no CO₂ emission which is responsible for global warming.

Hybrid and fuel cell vehicles are driven by motors not by engines, so conventional belt driven compressors should be replaced by the one in which motor is integrated. Because the frequency of driving motor is independent of the frequency of engine, the capacity variation can be attained by compressor itself. This makes it more efficient and effective.

Another effort to reduce CO₂ emission is to raise efficiency in order to reduce fuel consumption. In many cases, scroll compressor shows relatively good efficiency and low noise with the characteristics of no valve, smooth compression, and small variation of torque and so on.

Scroll compressor shows better volumetric efficiency compared to reciprocating compressor, because it doesn't have clearance volume and suction valve. But relatively long leakage path can lead to an internal leakage between compression chambers. The passage of internal leakage consists of radial and axial clearance. In many scroll compressors, the radial and axial compliant mechanisms are applied in order to reduce respective leakage. In this study we mainly focused on the back pressure control valve that plays an important role on axial compliant mechanism.

2. DESIGN OF BACK PRESSURE CONTROL VALVE

2.1 Type of Back Pressure

Figure 1 shows a back pressure structure that a chamber in a back side of orbiting scroll makes axial sealing between two scrolls. The back pressure chamber is filled with mid-pressure that is controlled by back pressure control valve. If back pressure force F_b is smaller than axial gas force F_a , orbiting and fixed scroll are separated. Consequently, enlarged axial clearance results in leakage loss. If F_b is excessively large, friction between orbiting and fixed scroll becomes large and it results in mechanical loss and wear. So proper design of back pressure is one of the most important factors in designing scroll compressor.

2.2 Measurement of Back Pressure

In order to estimate input power of a compressor with respect to back pressure, the test device was devised as shown in Figure 2. Discharge, suction, and mid-pressure chambers are linked with tube. In order to control back pressure using discharge gas, bypass valves are installed in discharge and suction tube. The openness of valve at discharge tube was set to be 6.5 kgf/cm^2 of the pressure difference of suction and back pressure chamber with the valve of suction tube closed. With the openness of discharge side valve fixed at that degree, adjusting the openness of suction side valve makes it possible to control the pressure difference with the value of $0 \sim 6.5 \text{ kgf/cm}^2$.

2.3 Optimum Back Pressure

Figure 3 shows the input power of a compressor with respect to pressure difference (ΔP_b) between back pressure and suction chamber.

In order to evaluate the effect of hysteresis, two cases of increase and decrease ΔP_b were considered. As a result, two cases showed almost similar outputs. When ΔP_b is 1.6 kgf/cm^2 , the compressor shows the minimum consumption of input power. If ΔP_b is increase to 6.5 kgf/cm^2 , the power input is also increased up to 20 % than that of the optimum case.

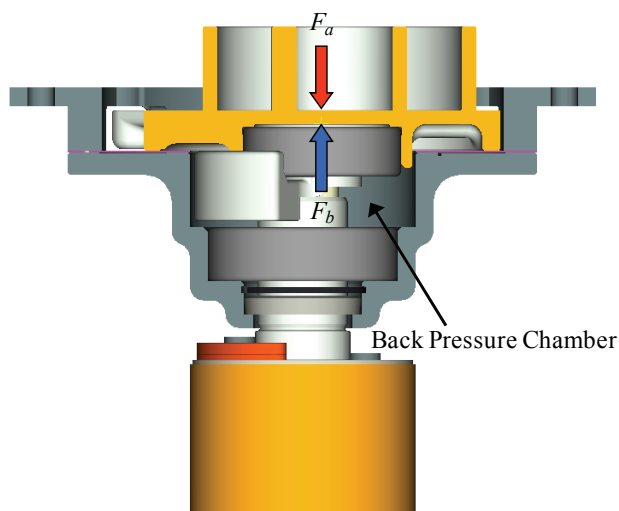


Figure 1: Structure of back pressure mechanism

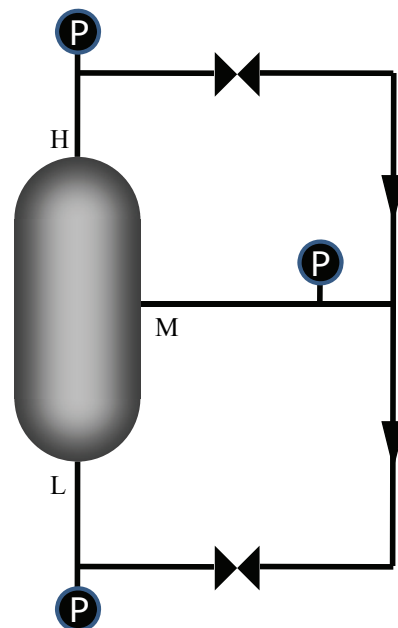
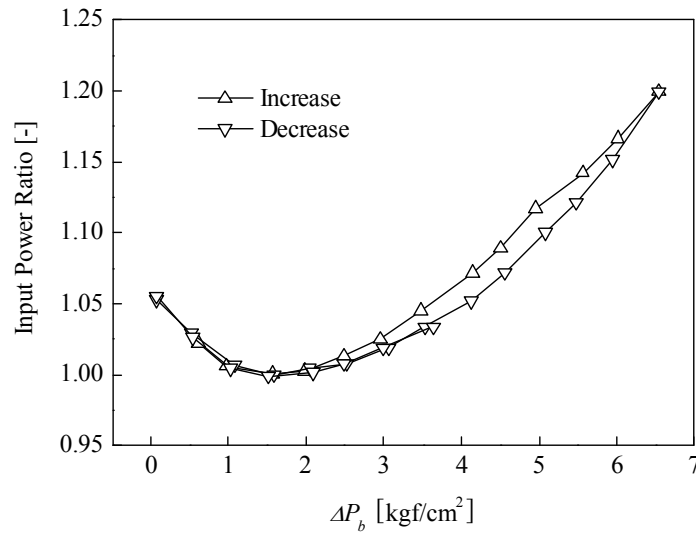


Figure 2: Device for back pressure test

Figure 3: Input power due to ΔP_b

2.4 Design of Back Pressure Control Valve

Figure 4 shows both conventional and modified design of back pressure control valve.

The valve consists of ball, spring and cylinder and is located in the crankshaft with the integrated design.

In conventional design, back pressure control valve was located at the pin side of crankshaft. It makes the ball eccentric from the rotating axis of crankshaft. The exerted centrifugal force to ball makes it hard to control mid-pressure at an accurate value. So the back pressure control valve was modified to integrated design and placed at the opposite side of crankshaft in order to make a room for placing a ball concentric to rotating axis of crankshaft. Also the contact lines between the ball and the cylinder was designed to have the same diameter with the hole. This leads to an easy maintenance of sealing edge as line contact and accurate evaluation of contact area.

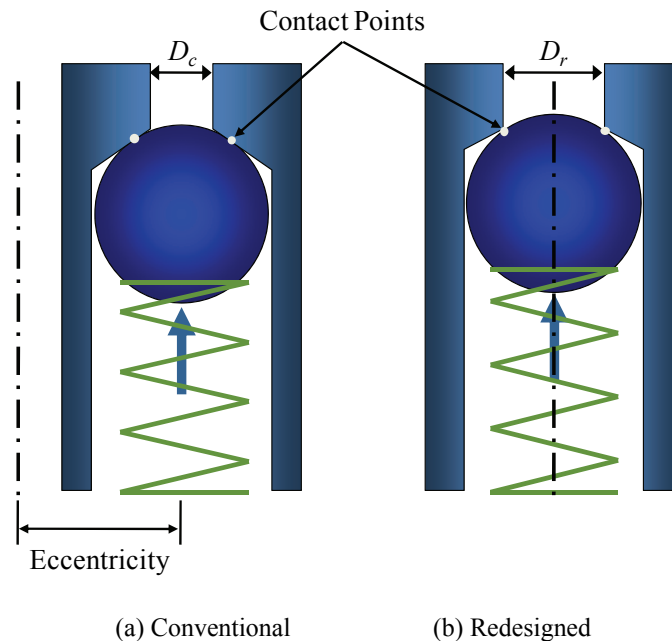


Figure 4: Installed shape of back pressure control valve

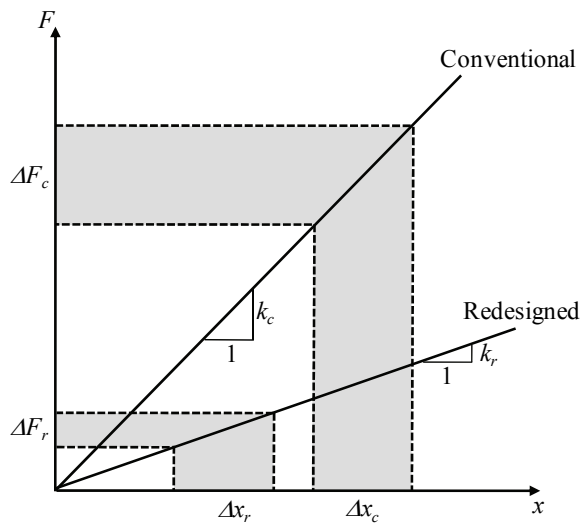


Figure 5: Reduction of stiffness variation

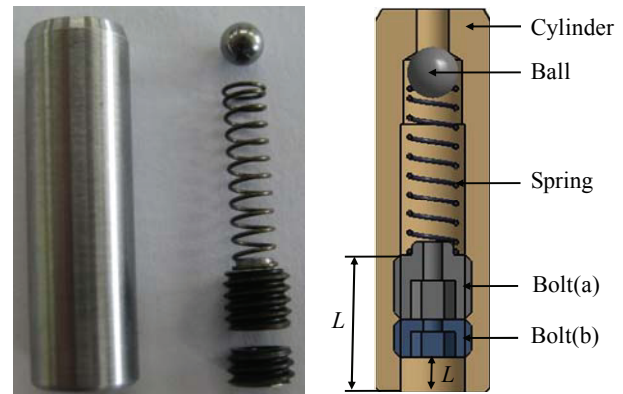


Figure 6: Structure of redesigned back pressure control valve assembly

Figure 5 shows the stiffness variation of the conventional and redesigned spring. As shown in this figure, using more flexible one, the variation of spring force can be reduced, and it results in more accurate control of back pressure. Figure 6 shows the modified integrated design of back pressure control valve.

3. APPLYING BACK PRESSURE CONTROL VALVE

3.1 Element Test

The element test equipment to evaluate control characteristics was devised as shown in Figure 7.

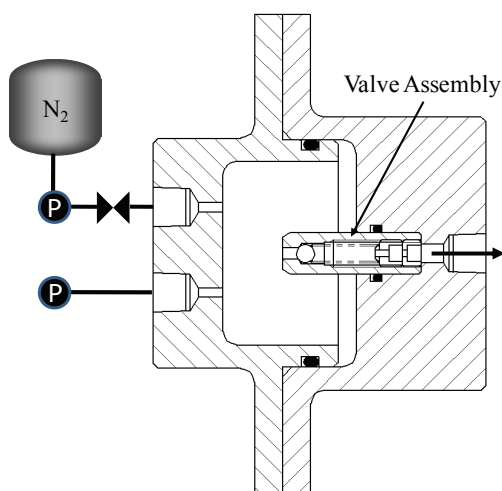


Figure 7: Element test equipment of back pressure control valve

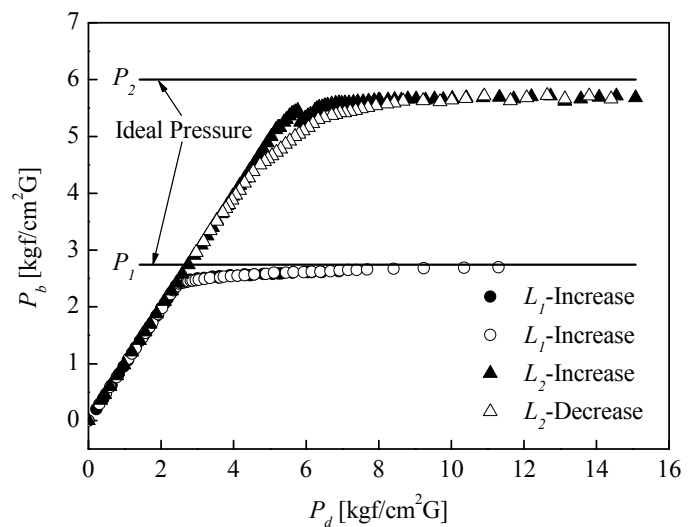


Figure 8: Element test result of back pressure control valve



Figure 9: Scroll compressor used in real mode test

In real compression state, separated oil at discharge plenum is supplied to back pressure chamber through orifice and is drained by back pressure control valve. In Figure 7, N_2 chamber plays a role of discharge plenum, and the isolated internal space corresponds to back pressure chamber. The valve means orifice located between discharge and back pressure chamber, and the flow rate was determined by the valve openness. So the pressure change of N_2 chamber with fixed openness of the valve makes it possible to control the back pressure.

Figure 8 shows the change of back pressure with varying pressure of N_2 chamber at proper piston length L_1 and L_2 . P_1 and P_2 are the calculated value of back pressure for piston length L_1 and L_2 respectively. For piston length L_1 , the same test was executed twice with increasing pressure only. However, for the case of piston length L_2 , the test was performed with increasing and subsequently decreasing pressure in order to investigate the presence of hysteresis effect. As a result, hysteresis was not found, and the measured back pressure value matched well with the calculated one. At a condition of steady back pressure, as discharge pressure grows up, back pressure is also raised.

3.2 Real Mode Test

A compressor in this study is inverter-integrated motor-driven horizontal scroll compressor as shown in Figure 9, and Table 1 indicates the detailed specifications.

Table 1: Specifications of scroll compressor

Items	Specifications
Displacement Volume	27.0 cc
Frequency Range	800 ~ 8600 rpm
Refrigerant	R134a
Motor	Sensorless BLDC
Inverter	180° Vector Control

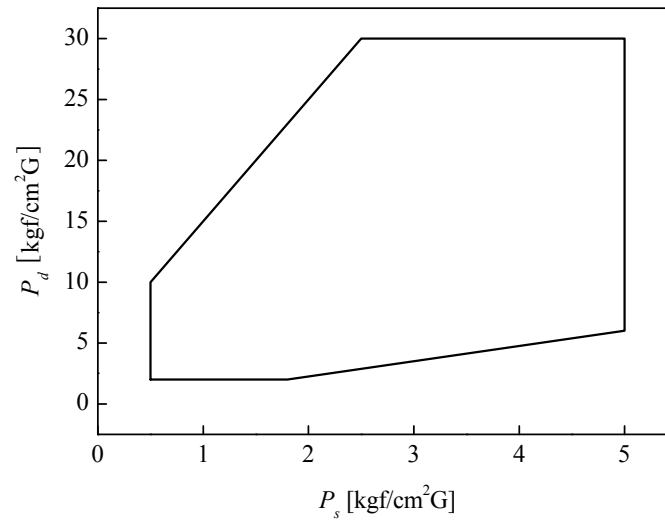


Figure 10: Operating envelope

Required operating region in automobile compressor is wide as shown in Figure 10. So appropriate back pressure should be determined in order to prevent wrap-separation and tilting for all the region. In the previous test, the optimum back pressure to minimize input power was obtained; ΔP_b is 1.6 kgf/cm² at $P_s = 2.0$ kgf/cm²G and $P_d = 15.0$ kgf/cm²G. But for the larger pressure difference between suction and discharge pressure, the bigger back pressure force is required in order to prevent wrap-separation and tilting, so the back pressure should also be larger. To be considered this operating range, the value of back pressure ΔP_b was determined to be 3.4 kgf/cm², where the piston length L was 10.2 mm. This real mode test was done at various operating conditions.

Figure 11 shows the behavior of back pressure with varying frequency. ΔP_b is retained constant about 3.5 kgf/cm², regardless of operating frequency, where the variation range of ΔP_b is under ± 0.08 kgf/cm². It means that it is possible to control ΔP_b in a range of 2.3 %. ΔP_b increased until 6500 rpm, and it decreased after that.

Figure 12 shows back pressure with varying discharge pressure. ΔP_b is kept steadily at 3.5 kgf/cm², regardless of discharge pressure.

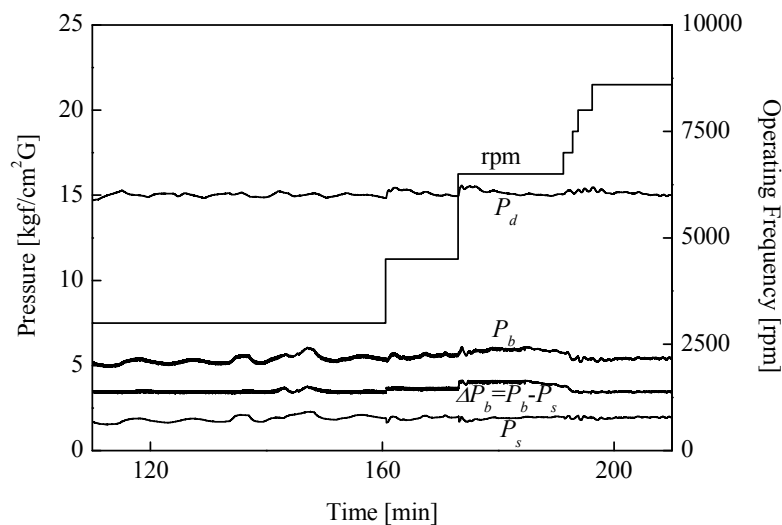


Figure 11: Back pressure with frequency varied

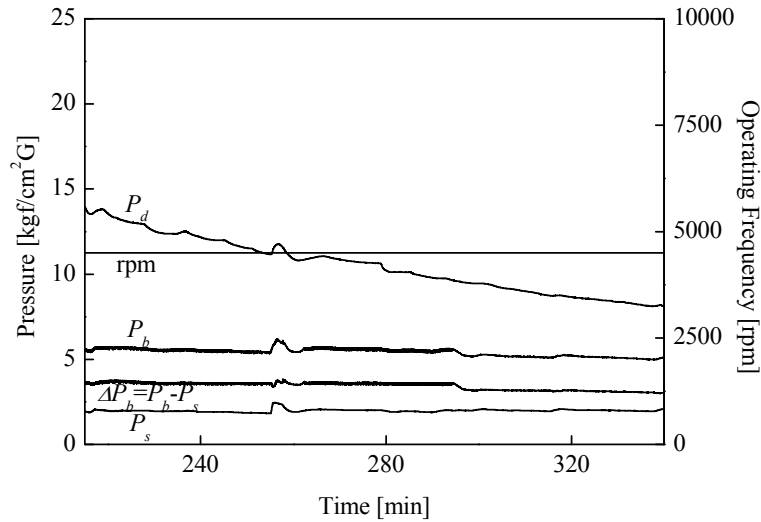


Figure 12: Back pressure with discharge pressure varied

4. CONCLUSIONS

As results of this study about design of back pressure control valve for automotive scroll compressor, conclusions were obtained as follows.

- The optimum value of back pressure could be obtained by minimizing input power as varying back pressure using simple test device.
- Integrated design of properly modified back pressure control valve was applied.
- An element test of modified back pressure control valve showed that calculated and tested value of ΔP_b were matched well as varying piston length.
- As a result of real mode test, back pressure ΔP_b was retained constant and was matched well to calculated value.
- Control characteristics of back pressure was as good as the variation of it was kept below the range of 2.3 %.

A design process of back pressure mechanism is divided into two steps. One is the optimization of back pressure value and the other is the minimization of oil-inflow to back pressure chamber. In this study the first step was discussed. The following step remains for future work.

NOMENCLATURE

D_c, D_r	diameter of a hole	(mm)
F_a	axial gas force	(N)
F_b	back pressure force	(N)
$\Delta F_c, \Delta F_r$	spring force	(N)
k_c, k_r	stiffness of spring	(N/mm)
L	piston length	(mm)
ΔP_b	back pressure	(kgf/cm ²)
P_d	discharge pressure	(kgf/cm ² G)

P_s	suction pressure	(kgf/cm ² G)
$\Delta x_c, \Delta x_r$	deformation of spring	(mm)

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